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Journal of the
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Proceedings of the American Society of Civil Engineers

CONTENTS

May, 1959

Papers

Journal of the
AIR TRANSPORT DIVISION
Proceedings of the American Society of Civil Engineers

NEW AIR TERMINAL FOR COLUMBUS, OHIO

G. E. Taylor, Jr.,[1] M. ASCE

SUMMARY

The new air terminal for Columbus, Ohio was dedicated on September 21, 1958. This article describes some of its outstanding features, and the criteria used in its design.

INTRODUCTION

In 1950, it became apparent to the airport management that the existing terminal building or, as then called, administration building was becoming inadequate for the air traffic needs of the City of Columbus and that, in view of anticipated increases in traffic, a new modern terminal building was needed. A master plan was prepared for the ultimate development of the airport, including the siting of the new terminal building and associated features, and decisions were made on the initial stage of the development.

Air traffic forecasts and peak-hour predictions were made to determine the volume of people to be handled within the building, including employees and all other operational personnel. With these figures as a guide and, also using other data available pertaining to number of airlines, concessionaire requirements, etc., a study was made to determine the type of terminal which should be provided. After considering two-level operation, single-level operation and various building configurations, the building as depicted in Plates 1, 2, and 3 utilizing single-level operation was decided upon. The plan was presented to the airlines, the Civil Aeronautics Administration, the Weather Bureau, the prospective concessionaires, and all other potential users and occupants of the building, and their approval secured before proceeding with the detailed plans for construction.

Note: Discussion open until October 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2014 is part of the copyrighted Journal of the Air Transport Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. AT 2, May, 1959.

1. Project Engr., J. E. Greiner Co., Baltimore, Md.

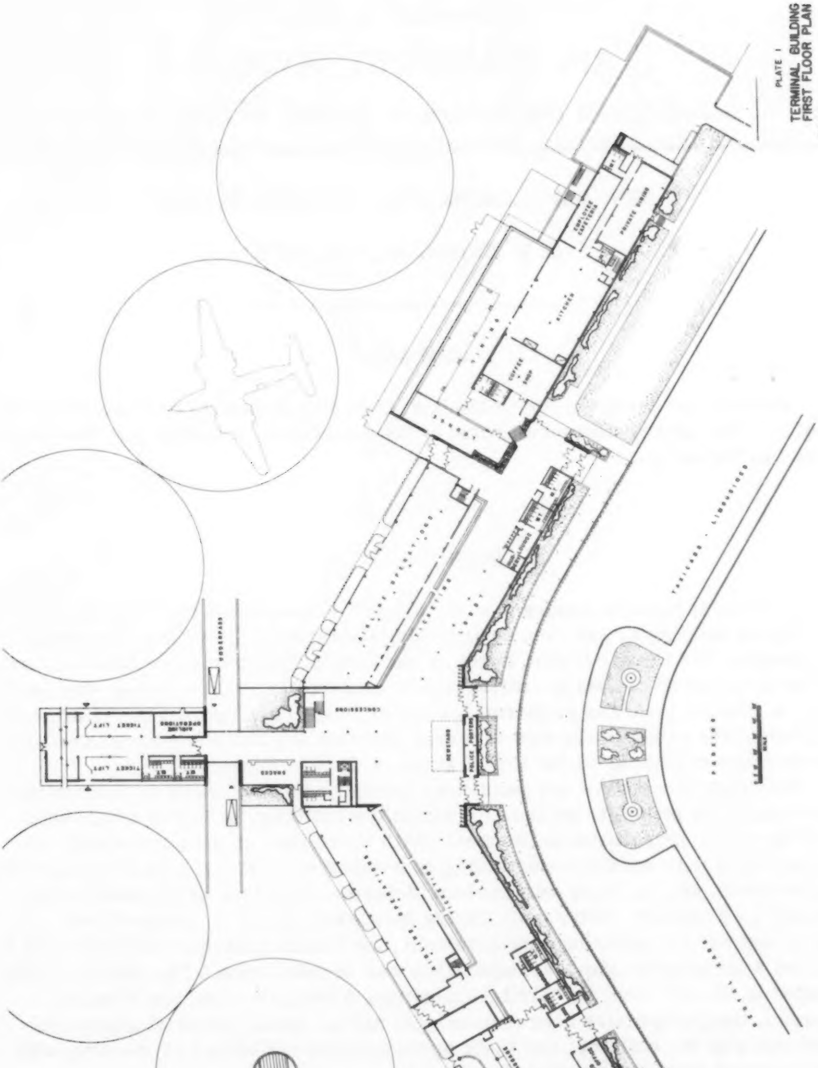

PLATE I
TERMINAL BUILDING
FIRST FLOOR PLAN

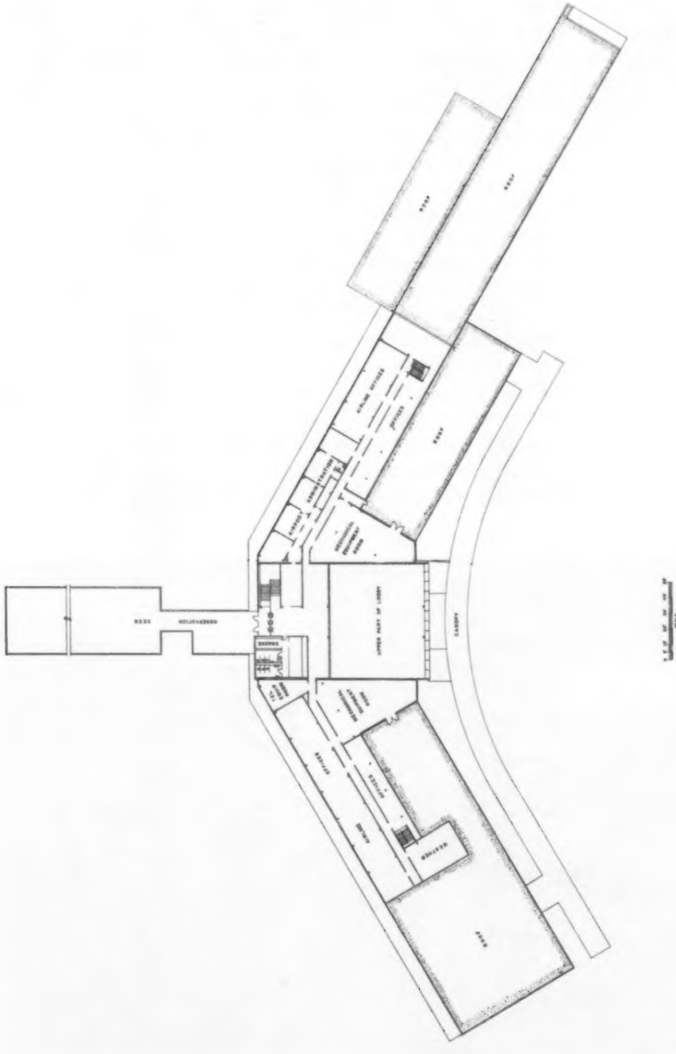

PLATE 2
TERMINAL BUILDING
SECOND FLOOR PLAN

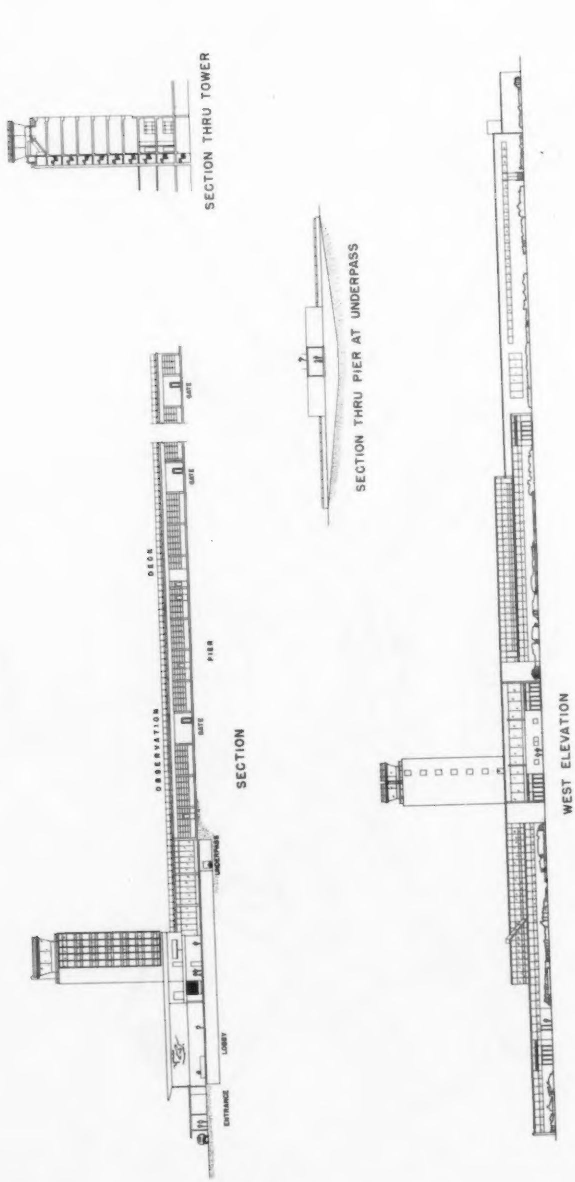

PLATE 3
ELEVATIONS & SECTIONS

General Description

The accepted plan is now serving three major airlines and two local or feeder airlines. The major airlines are provided three general types of space in the building. On the first floor of the main part of the Terminal, ticketing, and baggage checking and handling facilities are provided. See Fig. 1. Located on the second floor of the same part of the building are the reservations, flight crew lounges and training offices. In the pier are located the ramp operation offices and major communication centers. The local airlines and one of the major airlines have combined each of their operations so that second floor and pier spaces are not needed by all the airlines. Sufficient space has been provided in the initial construction for two or three more airlines depending on their future space requirements.

On the first floor, the building also houses dining facilities, waiting areas, concessionaire space, self-claim baggage area, ground transportation offices, police office and a branch post office. See Figs. 1, 2, and 7. On the second floor in addition to airline offices are located the Weather Bureau, airport administration offices, and other general office space for the Civil Aeronautics Administration, future airline requirements and other prospective tenants. The pier, designed principally as a loading facility, also contains adequate area at each gate to marshal passengers and for checking them ready for loading. See Fig. 3. The Control Tower above the second floor houses various C.A.A. agencies, navigational control equipment and the control cab. The first two floors are principally for employee facilities. The basement of the Control Tower contains the field lighting control equipment.

FIGURE 1. LOBBY VIEW SHOWING TICKET COUNTERS AND SEATING

FIGURE 2. INTERIOR OF DINING ROOM

Design Criteria

In establishing the criteria to govern the design and general arrangement of the building, the following items were given consideration:

1. Loading and unloading of passengers from ground transportation, including access to parking areas.
2. Loading and unloading aircraft.
3. Baggage handling and claim.
4. Safety and comfort of passenger while en route through the terminal.
5. Airline ticketing and offices, and apron operations.
6. Number of aircraft parking positions required initially and ultimately.
7. Concession areas.
8. Dining space requirements.
9. Weather Bureau needs.
10. Control Tower activities.
11. Observation Deck.
12. Public security and protection.
13. Administrative activities.
14. Maintenance.
15. Future expansion and changes.
16. General appearances.

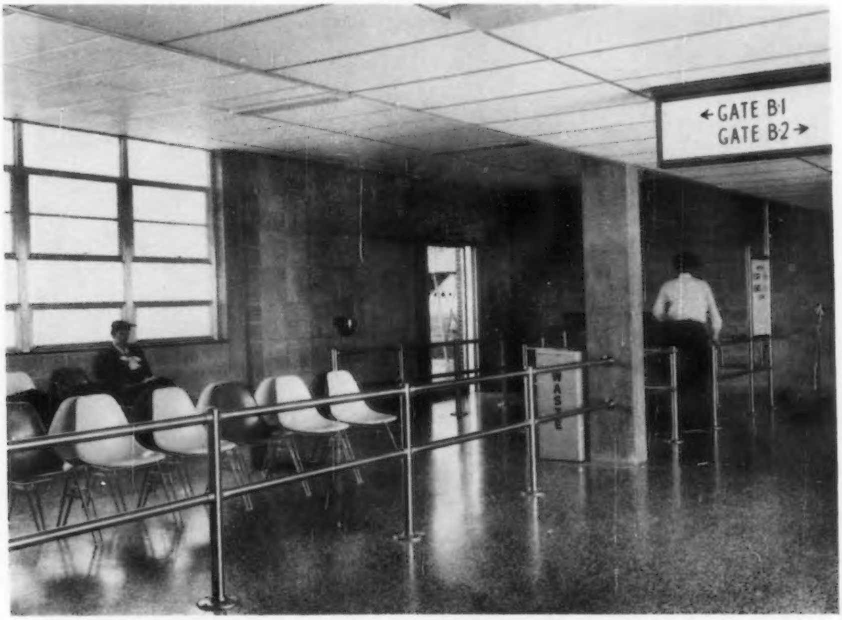

FIGURE 3. TYPICAL TICKET LIFT POSITION IN PIER

All loading and unloading of passengers from public ground transportation is done at the main entrances and exits along the westerly side of the building. Unloading is accomplished at the center or main entrance (see Fig. 4) and loading principally at the exit near the "Self-Claim Baggage" area. Taxicabs, limousines and rental cars are available at these locations for immediate loading. Private automobile operators may discharge their passengers at the main entrances, also, or drive directly into the parking areas which are within a short walking distance of the entrances. See Figs. 5 and 6.

Aircraft are loaded and unloaded at apron level along both sides of the pier and along the easterly side of the main part of the building. At present twelve aircraft loading positions are provided. These should be sufficient for immediate requirements and those of the foreseeable future. By expansion of the building to the north and south and the addition of two piers, the number of aircraft loading positions can be increased to an ultimate total of twenty-seven. In the pier, which will handle the larger plane loading operations, "ticket lift" areas are provided at each of the eight gates. These areas provide space for the marshaling of passengers prior to departure time and checking them in ready for instant boarding. See Fig. 3. They should aid materially in relieving the lobby ticket counters of some of their check-in duties, especially when a passenger's ticket has been validated at an off-airport office and no baggage checking is involved. The spacing between gates along the long axis of the pier is 160 feet.

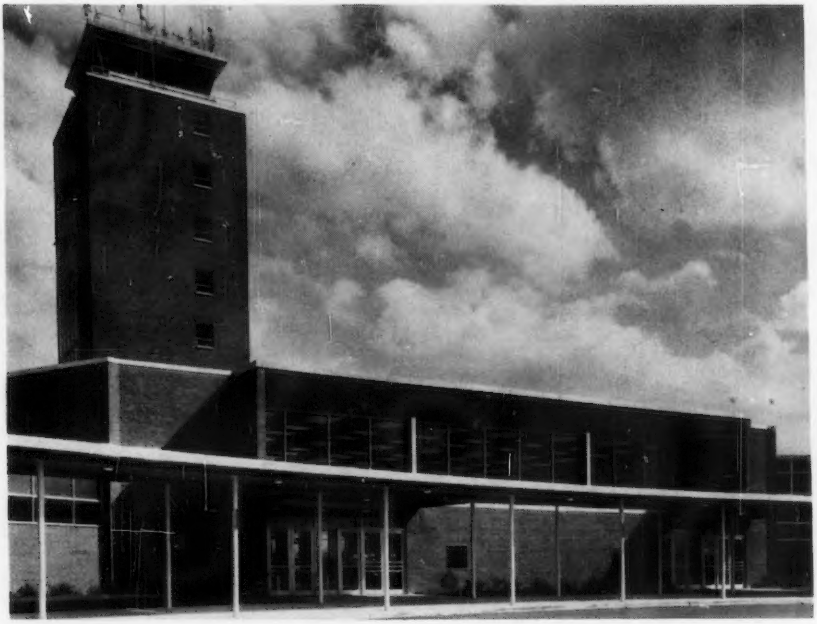

FIGURE 4. MAIN ENTRANCE AND CONTROL TOWER

Checked outgoing baggage is carted from a room in the rear of the ticket counters of each airline to the aircraft. Incoming baggage from all airlines is brought to one central claim area by cart and there it is placed on the counter for identification and claim by its owner. Theft control is exercised by an attendant at the exit gate of the barrier which encloses the area in front of the "self-claim" counter, by comparing claim tag with baggage tag. See Fig. 7. To eliminate interference with passenger traffic in the pier, an underpass was provided for the baggage carts and other ramp equipment. See Fig. 8.

The safety and comfort of the passengers and other members of the public while in the building were considered and adequate rest rooms, a nursery, concessionaire areas, waiting areas in the vicinity of ticket counters, and commodious dining facilities have been provided and located so as to be convenient and accessible to both traveler and visitor. See Figs. 1 and 2. All public areas and offices, except in the pier, are air-conditioned. Since the passenger is in the pier for such a limited time, it was not considered necessary to provide this comfort in this section of the terminal. Between the ground transportation vehicles at the westerly side of the building and the gate at each plane position, the passenger is completely under roof and protected from the weather.

The floor space requirements for the various airline operations were the subject of considerable study before arriving at the three general locations, i.e., first floor of main part of the building, second floor of the main part of the building and in the pier. The division was made on a functional basis and

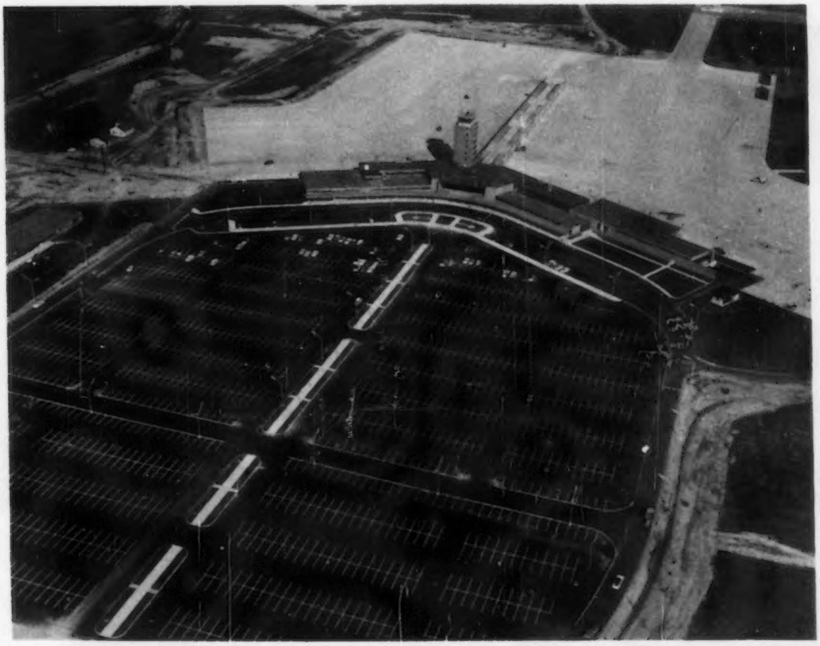

FIGURE 5. GENERAL VIEW OF TERMINAL AREA - LOOKING EAST

each area contains offices that are interrelated with each other and can work as a group semi-independently of the other groups of offices. The three locations are connected as required, however, by communication facilities and messenger tube services.

No underground apron facilities were installed except grounding connections at each of the aircraft parking positions. After economic studies were made by the airlines, it was decided that all servicing would be done by mobile ramp equipment. With the coming of jet aircraft, it appears possible, however, that underground fuelling may be required sometime in the near future. To provide for this eventuality a 48-inch diameter concrete pipe, through which main fuel supply lines could be installed, has been placed under a part of the aircraft parking apron. Branch lines can be jacked under the apron to the fuelling pits when their location is determined.

In making provisions for concession areas prospective concessionaires were contacted to ascertain their desirable requirements and adequate space and utilities provided for the areas to be occupied by the future tenant. Locations were chosen so as to be convenient to the public and to be advantageous to the concessionaire.

A dining room, coffee shop, employee cafeteria and beverage lounges were included in the building to satisfy the human needs and wants of the public and of the operating personnel. The dining room, located on the airfield side of the building, is constructed with two levels (see Fig. 2) so that all patrons can have a wonderful view of aircraft landing, taxiing, loading and unloading, and

FIGURE 6. GENERAL VIEW OF TERMINAL AREA - LOOKING WEST

FIGURE 7. SELF-CLAIM BAGGAGE AREA

servicing operations. The employee cafeteria, designed principally for the apron personnel, is strategically located with ready access to the apron and a view of the major part of the aircraft landing and operational areas.

The Weather Bureau was consulted to determine in detail their requirements and full facilities have been provided for the installation of the latest instruments for complete weather observation and forecasting.

The Control Tower requirements were determined almost entirely by the Civil Aeronautics Administration and the equipment for navigational and landing aids, and long distance communications was installed by this agency. In order to provide the utmost flexibility possible, all floors above the second are of cellular construction properly cross-headered to furnish underfloor wiring accessibility to all points. For accessibility from floor to floor a continuous vertical shaft was provided from the basement to the control cab atop the tower with doors to the shaft at each floor. Thus, by this complete flexibility and accessibility, changes, repairs, and additions can easily be made and the latest improvements in navigational aids can readily be added without disturbing the building structure or its multitudinuous and complex operations which are so essential to the safe and expeditious handling of air traffic into and around Port Columbus. The elevation of the control cab floor was determined after considering the ultimate development and so that the control personnel would have unobstructed view of all the runways and the more important sections of the taxiways, particularly at the intersection with runways, and at least a partial view of all parts of the field. Thus, complete surveillance of aircraft ground movements has been provided.

For the visitor who wishes to get a close-up look of the operations involved in handling aircraft on the apron and the passengers enplaning and deplaning, an observation deck was provided on the roof of the pier for its entire length. See Fig. 6. Suitable concession space was included at the entrance to the deck for the dispensing of refreshments.

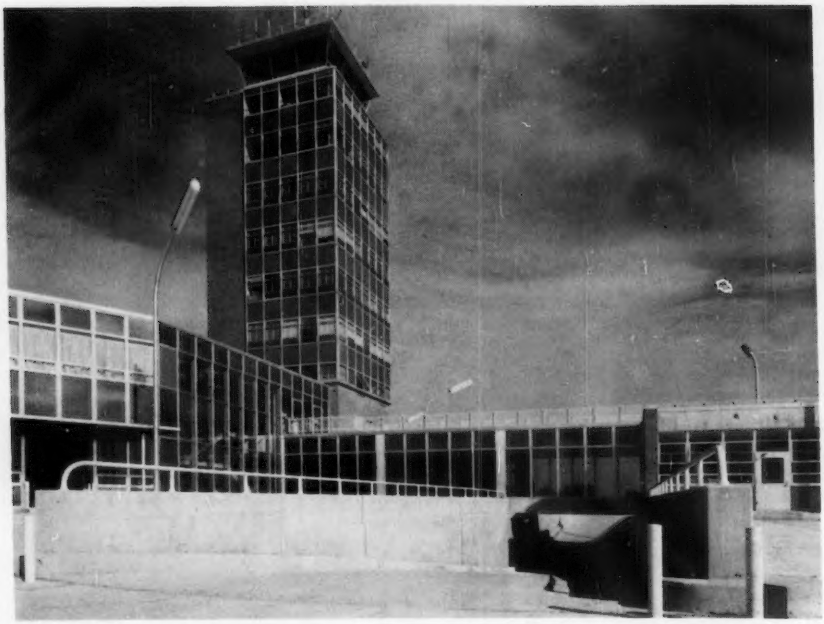

FIGURE 8. RAMP UNDERPASS-LOOKING NORTH TOWARDS PIER

For public security and protection an airport police force is required. To furnish proper quarters for their operations an office was provided near the main entrance and a locker room in the basement for changing into uniform.

The administrative offices for the airport manager and his staff are located on the second floor at the head of the main stairway. The offices overlook the major part of the airfield and are just a few steps from the balcony that overlooks the main lobby of the terminal. From this same vantage point much of the parking areas can be seen and a full view of the access road can be had. See Figs. 9 and 10.

In the architectural, structural and utility choice of materials and methods of installation, full consideration was given to minimizing maintenance, operation, and cleaning costs and to providing an installation which would be as flexible as possible in regard to future changes which are so frequently required in airline areas and concession areas. Masonry and similar type of hard surfaces were used wherever practicable, particularly in public areas to reduce maintenance and repair costs. For utmost in flexibility from an electrical standpoint, in addition to the metal cellular floor system used in the Control Tower, a concrete cellular floor system was utilized in most of the remainder of the Terminal. To provide ready access to ceiling areas where future changes are expected, a suspended ceiling system was used with removable acoustical tile. By the removal of the individual pieces of tile, simply by lifting them out of their supports, the complete underside of the slab above can be made accessible. This is particularly helpful when the ceiling

FIGURE 9. CENTRAL LOBBY FROM BALCONY - PARKING AREA IN BACKGROUND

lighting is to be modified or an air conditioning outlet must be relocated. For access to the underside of the first floor, where there is no basement, crawl space has been left under the entire area of the floor. This provides ready access to any point for major electrical changes such as relocation or addition of main feeders or load centers and for access to the main parts of the mechanical systems.

Electric power supply to the building is from two independent sources. In the event of failure of one source, automatic switchover-gear transfers the electrical load to the alternate source.

While the scope of the architectural treatment is very limited for a building so functional in nature as this, individual areas were given consideration and generally the appearance of the Terminal is very pleasing in actuality when viewed from almost any angle.

Construction

The Terminal was constructed under two separate contracts. Since the initial funds available for construction were sufficient only for the erection of the Control Tower, this part of the Terminal was constructed first. The old tower was entirely inadequate and completely mislocated in regard to the airport operations and the need for a new control tower was very urgent for air safety reasons. The new Control Tower was in operation for several years before the remainder of the Terminal was completed and put into operation. During this period extreme caution and care had to be exercised to keep this vital installation operative. Close cooperation of all concerned was necessary in working around the tower and in making connections to it as the various utilities were incorporated into the systems of the entire building.

FIGURE 10. CENTRAL LOBBY SHOWING BALCONY

The Control Tower structure and the main portion of the Terminal is a steel frame with brick and aluminum panel facing. The pier framework is principally a series of concrete bents connected by precast concrete cellular floor slabs with a brick facing. For future expansion within the original limits of the Terminal, the structure was designed to permit the second floor offices to be extended to the northerly limits of the building and for a second floor on the entire pier.

The features which appeared to expedite construction considerably was the use of pre-cast or pre-fabricated cellular floor systems. The absence of the usual form work obstructions and the availability of a deck upon which all trades could work simultaneously appeared to be a tremendous advantage to everyone.

Floor Space

The total area of floor space provided is 129,040 square feet. A brief analysis of the usage of this space is as follows:

Use	Area (sq.ft.)	Percentage of Total Area
Airlines	42,880	33.2
Rentable Areas	21,360	16.7
Post Office	650	0.1
Weather Bureau	1,210	1.0
Civil Aeronautics Adm.	5,550	4.3
Public	34,470	26.8
Utility	20,860	16.3
Management	2,060	1.6
Total	129,040	100.0

ACKNOWLEDGMENTS

The initial planning, design and supervision of construction of the Terminal, as well as the pertinent airport features which supplement its operations, were all accomplished under the guidance and professional services of J. E. Greiner Company. For certain aspects of the problems involved they employed other firms as consultants or associates. Landrum and Brown advised on space requirements and functional layout of the building. Office of James R. Edmunds, Jr. prepared the architectural plans and specifications and furnished advisory services for supervision of construction. Working with the architects were the firms of McNeill and Baldwin for the mechanical and electrical installations and the Office of Van Rensselaer P. Saxe for the building structure. Mr. Thomas J. Tully, an architect resident in Columbus, was employed as a consultant for local problems that arose during the construction phases. The entire project was under the direction of Mr. Floyd C. Redick, Director of the Department of Public Service of the City of Columbus and Mr. F. A. Bolton, airport manager and resident representative of the City of Columbus Aviation Commission.

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Proceedings of the American Society of Civil Engineers

SPECIAL PAVEMENT REQUIREMENTS FOR JET AIRCRAFT OPERATIONS

Belmon U. Duvall[1]

SYNOPSIS

The exhaust heat and blast factors in the ground operations of modern jet aircraft applicable to both commercial and military (U.S. Air Force) categories are described. The procedures followed by the Corps of Engineers, U.S. Army, for the development of data required to establish performance requirements and capabilities of conventional portland cement concrete and bituminous concrete pavements subjected to jet aircraft operations, are presented briefly. The use of non-standard paving materials and construction methods is described. The possible critical areas of airfield facilities pavements are defined.

INTRODUCTION

Since shortly before the end of World War II, aircraft design and propulsion methods have changed materially. New concepts in both fields are being developed to operational status at a very rapid rate. These developments have now reached a point where the commercial carriers can justify, economically, the use of high speed jet aircraft for medium to long hauls and thereby provide the type of service which modern living demands.

The rapid developments in jet propelled aircraft, coupled with (1) an incomplete understanding of the capabilities and/or limitations of the two conventional paving mediums to be subjected to such usage, and (2) the paucity of specific data on jet aircraft and jet engine operational characteristics, has produced a highly controversial situation as to the type of pavement required.

Note: Discussion open until October 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2015 is part of the copyrighted Journal of the Air Transport Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. AT 2, May, 1959.

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A cursory evaluation in about 1950 of early military jet aircraft designs, propulsion units, and operational characteristics indicated that a problem might exist in the future in providing adequate pavements and that a comprehensive unbiased study was warranted. These studies for the special requirements, if any, for future United States Air Force pavements were assigned by the Chief of Engineers jointly to the Flexible Pavement Laboratory of the U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, and to the Rigid Pavement Laboratory of the Ohio River Division Laboratories, U.S. Army Engineer Division, Ohio River, Cincinnati, Ohio.

Investigations

The studies of the Corps of Engineers have been in three broad categories:

1. Aircraft and propulsion unit characteristics, aircraft ground movement, and dead stand operations.
2. Effects of heat and blast on pavements.
3. Materials studies for heat and blast resistant surfaces, construction methods, and specifications.

Aircraft and Propulsion Unit Characteristics

To a degree the attitude of military aircraft has been influenced by the using service requirements and the mission to be accomplished. The jet exhaust pavement impingement angles of the early U.S. Air Force jet aircraft, mostly in the fighter and fighter-bomber categories, can be considered severe as to potential pavement damage in comparison with current types, and most of those now in the developmental stage. In general, the U.S. Navy jet aircraft have been and are more severe than those of the U.S. Air Force.

The ground operational characteristics of the U.S. Air Force jet aircraft have been determined by means of (1) studies of detailed aircraft plans, (2) actual measurements of exhaust nozzle diameter, height, and center line angle with respect to pavement surface, including changes in attitude during power run-ups, (3) aircraft time-movement studies at selected Air Force Bases, including timing of dead stand operations, such as starting and maintenance run-ups, (4) fuel spillage approximations, and (5) pavement surface temperature measurements for both bituminous and portland cement concrete pavement.

The timing of these early studies was such that insofar as feasible the information could be obtained in advance of each new type aircraft reaching full operational status at the various bases. In the early stages of the studies, both types of conventional pavements were constructed at Eglin Air Force Base with the necessary instrumentation for recording temperatures at the pavement surface and at several depths in selected areas. Later these determinations were made at the Air Force Flight Test Center, Edwards Air Force Base, in order to provide data prior to the aircraft reaching production status. The installation at the Flight Test Center is a semi-permanent facility having a special rail-movable chock system for restraining the aircraft during high power run-ups and a multiple channel flight recorder for temperature recording.

The jet exhaust pavement impingement angles for the pre-1954 U.S. Air Force aircraft, ranged from 0° to 8° below the horizontal and the measured

height above the pavement of the exhaust center line varied from 40 inches to 86 inches. The thrust of these early jet engines was considerably less than currently operational engines—ranging from 4,000 to 6,000 pounds; further, afterburners for additional thrust of short duration were used on only two of the pre-1954 aircraft. The U.S. Air Force aircraft which have become operational since 1953; i.e., those in the fighter group, bearing designations of F-100 and higher, the heavy jet bombers, and jet tankers, although powered with two to three times higher thrust jet engines with possibly two exceptions, have become much less severe as to potential heat and blast damage to pavements. This is due to the fact that jet engine exhaust centerline is in many cases almost parallel to or angled upward and at an appreciable height above the pavement.

Since it is axiomatic that any damage to pavements would be a tail pipe diameter-time-power-impingement angle function, a Time-Movement Study was one of the early phases of the overall investigation. This study was made at 14 airfields and encompassed both fighter and bomber operations. Recent spot checks indicate that the data is generally applicable to current aircraft. Although clocked operations varied more than 50 per cent, plus or minus, a summary of the statistical analysis of the data from over 700 operations showed the times given in Table 1 could be considered as normal for ground operations, excluding taxiing movements prior to take-off.

Table 1

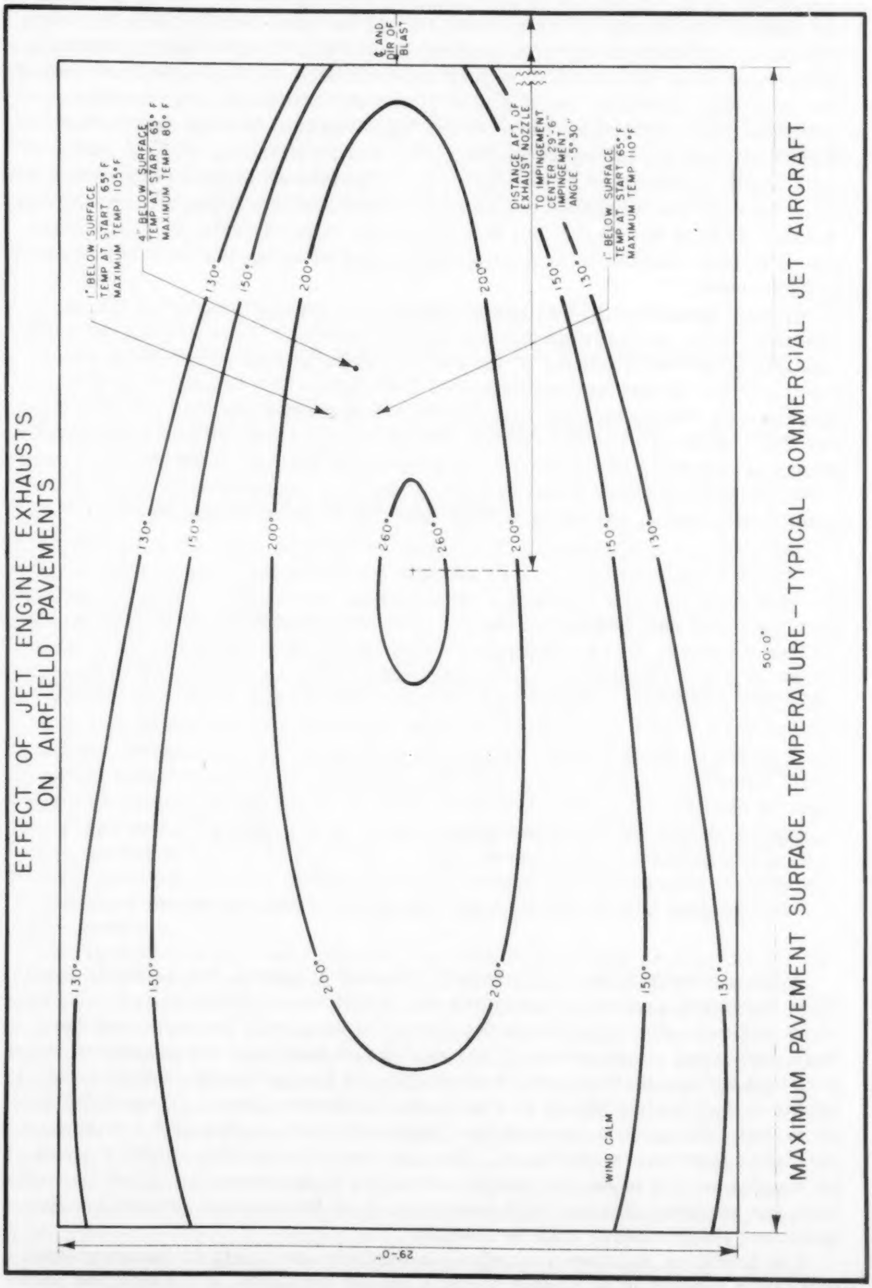
Ground Operating Times - Non-Moving Jet Aircraft

	Starting		Pre-Take-Off		Maintenance	
Engines	%Power	Minutes	% Power	Minutes	% Power(1)	Minutes
Single	Idle to 60	3.5	Idle to 100	1.5	Idle to 100	14.0
Multiple	Idle to 60	10.0	Idle to 100	2.5	Idle to 100	14.0

(1) Power setting varied with fluctuations following no set pattern.

It is extremely difficult to predict, with any accuracy, the probable maximum pavement surface temperature which will occur during power run-ups of jet engines. Several procedures for estimating such temperatures have been developed. Comparison of calculated and measured temperatures indicate that actual measurement is desirable. In the pavement surface temperature distribution shown in Fig. 1, the isotherms from a group of forty almost simultaneous measurements repeated over a period of 7.5 minutes until the temperature stabilized. The maximum temperature (260° F.) can be similar to that to be anticipated with some of the commercial jet aircraft. Data has not been obtained with suppressors on the exhaust nozzles but the pavement temperatures may be lower.

The trends in military aircraft as to attitude and height of the propulsion units with respect to pavement surface, thrust available, and measured pavement surface temperatures are summarized in Table 2. Similar information



MAXIMUM PAVEMENT SURFACE TEMPERATURE – TYPICAL COMMERCIAL JET AIRCRAFT

FIGURE 1

Table 2

Jet Engine Characteristics and Pavement Surface Temperatures

	USAF Fighter Aircraft Pre. 1954(1)	USAF Fighter Aircraft Current(2)	USAF Bombers and Tankers (2)	Commercial Aircraft(1)
Exhaust ℄ above pavement.	40" to 60"	62" to 97"	63" to 100"	61" to 90"
Exhaust-Pavement Impingement Angle(3)	0° to -8°	-6° to $+3^\circ$	-1° 30' to -5° 30'	-3° 30' to -5°
Single Engine Thrust, 1000 Pounds.	4 to 6	9.5 to 23.5	6 to 15	11 to 16.5
Measured Pavement Surface Temp. F°	165 to 255	155 to 300(4)	185 to 330(5)(6)	200 to 300(7) 145 - 185(8)

NOTES:

(1) Non-afterburner equipped and without suppressors.
(2) Does not include non-production line aircraft.
(3) Minus (-) below horizontal; plus (+) above horizontal.
(4) Afterburner operation - Maximum 900° F.
(5) Maximum for obsolete Light Bomber - 350° F.
(6) Aircraft similar to Boeing 707, but slightly less severe impingement angle; 185° to 200° F.
(7) Estimate based on military A/C of similar attitude, thrust and height of exhaust ℄ above pavement. No noise suppressors on engines. Engine maintenance run-up conditions may increase maximum pavement surface temperatures somewhat.
(8) Estimated for commercial aircraft with noise suppressors on engines.

for commercial jet aircraft expected to be operational in the United States in the very near future is included in Table 2. The presentation of data in full detail would be quite voluminous and serve no useful purpose. The characteristics delineated in Tables 1 and 2 for the several jet aircraft categories, and the temperature distribution shown in Fig. 1, are the principal ones for consideration in evaluating potential effects of commercial jet aircraft operations on pavements.

Effects of Heat and Blast on Pavements

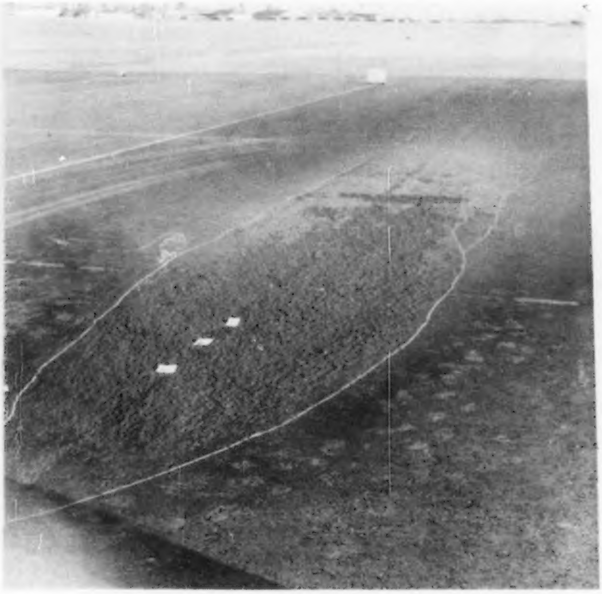
The reported instances of jet aircraft operations damaging airfield pavement surfaces are far too numerous to even partially list or describe herein. In some cases, regardless of the degree of surface erosion, and particularly on bituminous pavements, even minor damage has been unfortunately described as a complete pavement failure. Undoubtedly, many erroneous reports and rumors of damaged pavements, both bituminous and portland cement concrete, have been generated through conclusions based on incomplete information, inability to obtain facts, a lack of knowledge of the operating conditions involved, and misinterpretation of the factors involved.

Extensive studies have demonstrated that bituminous pavements are not damaged by moving jet aircraft. Properly designed and constructed bituminous pavements will withstand reasonably prolonged dead stand or static operations of jet aircraft providing the pavement surface temperature attained is less than 300° F. and the blast impingement angle is not severe; i.e., less than 6 degrees. It will be noted that this surface temperature is considerably above the Softening Point (ASTM) of paving grade bitumens. At the 300° F. surface temperature, although the asphaltic concrete is not eroded, sufficient softening may occur to cause an almost imperceptible displacement (tire imprints) when the area is trafficked immediately after cessation of jet engine run-ups.

With non-moving jet aircraft operations when bituminous pavement surface temperatures exceed 300° F. the degree of damage; i.e., surface erosion, is a function of blast temperature and velocity, impingement angle, and duration of exposure. It has been observed that in static Maintenance Run-ups the same jet engine with a 2 degree increased impingement angle, although mounted 14 inches higher above the pavement surface, will increase pavement surface temperatures to about 350° F. This increase in pavement surface temperature of less than 50° F. meant the difference between minor removal of surface fines in a bituminous pavement surface and erosion to a maximum depth slightly greater than 1-inch.

The degree of erosion of bituminous pavement occurring with a 350° F. surface temperature during a 21-minute Maintenance Run-up of an 8 degree impingement angle jet aircraft is illustrated in Photo No. 1. A similar Maintenance Run-up operation of another jet aircraft having the same class jet engine, but when the impingement angle was slightly less than 6 degrees, caused no visible damage to bituminous pavement.

A few instances of jet aircraft operations damaging portland cement concrete pavements have been reported and investigated. Laboratory materials studies have been correlated with the investigations of such damage. Many factors influence the ability of rigid pavements to withstand the heat and blast of jet operations. These factors are principally surface temperature attained, type of aggregate and cementing medium used, pavement age and

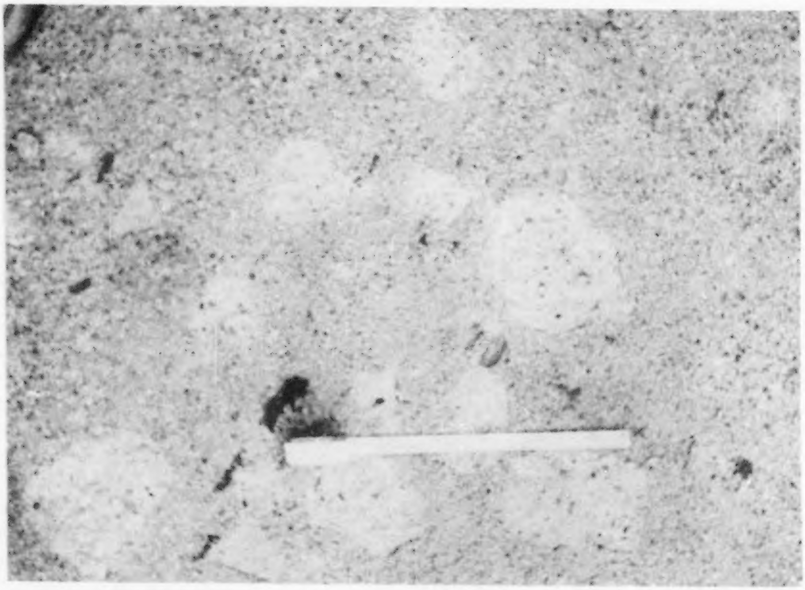


Typical Pattern of AC Pavement Erosion Due to Maintenance Run-up Operation.

Photo No. 1

moisture condition, and duration of heat and blast. In general, it may be stated conservatively that rigid pavements are usually undamaged by jet operations providing the surface temperatures do not exceed 800° to 1000° F. This temperature limitation is applicable to portland cement concrete made with certain siliceous aggregates. The use of other aggregates similar to those in the basic igneous rock category, selected crushed non-glassy blast furnace slags, and selected manufactured semirefractory types of aggregate, will provide pavements reasonably resistant to pavement surface temperatures in the 1000° to 1500° F. range. Typical instances of minor surface damage; i.e., less than 1/4 inch depth, to portland cement concrete pavements in which undesirable siliceous aggregates were used are illustrated in Photos No. 2 and No. 3. A typical case of pavement joint seal removal by jet exhaust heat and blast is shown in Photo No. 4.

It will be noted in the typical heat and blast pavement damage cases illustrated, the affected portions can be classed as small isolated areas of the airfield pavement system. These instances of isolated area surface damage can be reduced or eliminated by a restricted operational policy requiring the mandatory use of specific areas for prolonged high thrust and/or maintenance run-up operations. At the present time only several military jet aircraft have operational characteristics which will under some operational conditions cause pavement surface damage. Future advances or changes in



Minor Surface Scaling of Recently Constructed PCC Pavement Due to Heat and Blast of Jet Exhaust.
Photo No. 2

commercial jet aircraft design and propulsion units could materially change the present concept of the suitability of conventional pavements for normal operations of commercial jet aircraft.

Until recently, the spillage of jet fuel posed somewhat of a severe problem. Observations of early jet operations showed that considerable fuel spillage occurred mainly on parking aprons when engines were cut off and during refueling operations. Rigid pavements, except for joint seals, were not affected by jet fuel spillage. In general, dense graded, well constructed, aged asphaltic concrete pavements were not seriously affected, except in parking and refueling areas. Due to the low volatilization rate, the jet fuel caused surface softening of the bituminous pavement; however, unless repeated spillage occurred in the same areas or the areas were subjected to jet exhaust blast, the quality of the pavements was unaffected after cure-out of the softened asphalt. Improvements in jet engine fuel controls and changes in the fuel formulations have reduced the potential damaging effect of fuel spillage to where it is a minor consideration, except in refueling areas.

The critical area requirements of an airfield pavement system with respect to potential damage by jet exhaust heat and blast, will differ appreciably between military and commercial operations. Certain fighter and fighter-bomber aircraft operations can impose severe heat and blast conditions on pavements, due to the comparatively more severe blast impingement angle and the lesser height of the jet exhaust center line above the

PCC Pavement Surface Erosion Due to Heat and Blast of Jet Exhaust. Age of Pavement - Approximately 13 years.
Photo No. 3

pavement surface. At times, jet engine starting operations on the aprons require prolonged or intermittent full power operations; also routine preflight checks up to full power are made on the taxiway approaches to the main runway or on the runway ends. The most severe heat and blast on pavements for these aircraft occur during Maintenance Run-up operations, which are made under no standard conditions and therefore may be prolonged, or of short duration, with variable power settings up to and including full power. The trend for Military Aircraft is to conduct Maintenance Run-up operations in pre-selected areas to reduce pavement damage to a minimum and at the same time reduce noise level in high density personnel areas. The medium and heavy jet bombers and jet tankers impose considerably less, in fact relatively innocuous, heat and blast on pavements. The commercial jet aircraft planned for operation in the immediate future should impose heat and blast conditions no more severe than these latter types of military aircraft.

Currently, the requirements as to pavement type with respect to new construction and extensions of existing facilities for military aircraft are based primarily on loading and frequency of operations, or pavement life. It is generally required that the primary taxiway system, parking aprons, refueling areas, and runway ends be portland cement concrete.

Typical Blow-out of Softened
Joint Seal Due to Jet Exhaust.
Photo No. 4

Materials Studies

The heat and blast resistant paving materials studies have been a joint effort of the two Corps of Engineers pavement laboratories, the Flexible Pavement Laboratory, U.S. Army Engineer Waterways Experiment Station, and the Rigid Pavement Laboratory of the Ohio River Division Laboratories, U.S. Army Engineer Division, Ohio River.

The objectives of the studies have been, (1) determination of the capabilities and limitations of the two conventional types of airfield pavements and the materials used in their construction, (2) development and/or adaptation of refractory materials for critical areas of airfield pavements, and (3) preparation of materials and construction method specifications. The scope, procedures, and findings in these studies are normally of interest to special groups and considered outside the intent of this paper.

On the basis of the extensive laboratory and field studies of the Corps of Engineers, and the numerous cooperating producers of refractory materials, a series of pavement test installations have recently been completed at K. I. Sawyer, McClellan, and Langley Air Force Bases. The purpose of the field tests is, of course, to (1) confirm or refute the laboratory findings, and (2) provide adequate information to properly design and construct heat and blast resistant pavements for critical areas when and if such are required. The materials and systems selected for the test installations are intended to

provide thin pavement overlays resistant to heat and blast in the 1000° to 3000° F. surface temperature range.

The thin heat and blast resistant overlays constructed during the past year include trap rock (New Jersey and Wisconsin), natural emery, and expanded shale in combination with calcium aluminate cement, and commercially available castable refractories. An area of super duty, spall-resistant refractory brick, bonded to the base pavement with special epoxy resin mortars, was also included in the Langley Air Force Base test areas. The trap rock, natural emery and expanded shale aggregates were 3/8 inch maximum size and uniformly graded from coarse to fine. The castable refractory and refractory brick were procured under special performance specifications prepared by the Ohio River Division Laboratories. These two latter materials, if furnished in accordance with the usual American Society of Testing Materials, or the Federal Specifications, would not necessarily be satisfactory, as the use conditions intended are unique in comparison with conventional use of refractories.

The principal construction problem encountered has been to obtain adequate bonding of the thin refractory (both castable and brick) overlays to the base pavements. The conventional cement grout bonding method has proven unsatisfactory. In the third test installation the bonding mortars used were special formulations of epoxy and epoxy-polysulfide polymers with suitable curing agents. Pilot field tests made in October 1957 and the August 1958 test installation already indicate the superiority of the epoxy mortar bonding system for thin overlays.

At the present time the overall results of these materials studies have very limited application for currently operational jet aircraft, but are applicable to certain missile testing and launching facilities.

SUMMARY

The results of the studies, observations, laboratory and field tests of the effects of jet aircraft operations on pavements, may be summarized as follows:

(1) Military jet aircraft blast approaches and in some instances exceeds the critical erosion temperature (300° F.) for hot-mix asphaltic concrete pavements only at the runway ends and on aprons where maintenance run-ups are made.

(2) Repeated jet fueld spillage can produce significant distress in dense hot-mix asphaltic concrete in parking and refueling areas. Changes in jet engines, handling systems, and fuel formulations have reduced the frequency of fuel spillage damage to pavements. The areas affected are usually relatively small, but a pavement resistant to jet fuel is highly desirable.

(3) Pavement surface temperatures induced by jet engine exhaust normally do not affect portland cement concrete unless 800° to 1000° F. temperatures are exceeded, except that joint seals may be softened and blown out. Jet fuel spillage does not affect portland cement concrete pavements except that jet fuel resistant joint seals are required in certain areas.

(4) Heat, blast, and jet fuel resistant materials and construction methods have been developed for use in critical pavement areas, when and if such are required for jet aircraft operations.

(5) The critical pavement area requirements with respect to heat, blast

and fuel spillage differ appreciably for military and commercial jet aircraft. The current critical areas for military aircraft, based on load-capacity factors, as well as those discussed herein, comprise the parking and refueling aprons, primary taxiways and runway ends. The early operational commercial jet aircraft, based on information available at this time, should impose no critical area pavement limitations, except for refueling areas and possibly jet engine maintenance run-up facilities.

(6) Since the applicable data, obtained from actual tests, for commercial aircraft are quite limited, the probable exhaust effects on pavements must now be based principally on deductions from related experience and judgment. In view of this lack of specific information and constant developments in the jet field, it is suggested that a facility similar to that used at the U.S. Air Force Flight Test Center for the study of jet exhaust effect, would be most advantageous and worthwhile. Such a facility might be cooperatively sponsored and operated by the aircraft manufacturers, owners, and airport operating authorities.

ACKNOWLEDGMENTS

The studies discussed herein have been conducted under the supervision of the Office, Chief of Engineers, as a part of the overall development of design criteria being accomplished for Military airfield pavements. Messrs. T. B. Pringle and W. C. Ricketts of the Airfields Branch of the Office, Chief of Engineers, supervised the study. Mr. F. M. Mellinger, Director, Ohio River Division Laboratories, U.S. Army Engineer Division, Ohio River, directed the actual conduct of the Rigid Pavement portion of the investigational program. Guidance for the special paving materials development is furnished by Dr. Samuel Zerfoss, Professor John L. Carruthers and Alfred W. Allen, Mr. Stuart Phelps, and the Research Directors of the cooperating refractory producers. The laboratory and field work was accomplished by the Corps of Engineers' Flexible Pavement Laboratory, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, and the Rigid Pavement Laboratory, U.S. Army Engineer Division, Ohio River, Cincinnati, Ohio. The U.S. Air Force provided and operated all aircraft used in these studies and assisted in all tests and observations at airfields. Acknowledgment is also made for test results and data received through channels from the U.S. Navy and the British Air Ministry. The Asphalt Institute and the Portland Cement Association have also been most helpful in furnishing information and data.

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PAVEMENT DESIGN FOR COMMERCIAL JET AIRCRAFT[a]

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and P. F. Carlton,[3] A.M. ASCE

SYNOPSIS

Pavement requirements are given in the form of Design Charts for both rigid and flexible pavements. The design curves cover a range of loadings for the Boeing 707, the Douglas DC-8 and Convair 880 Commercial Jet Aircraft. The basis and application of the pavement design curves are fully explained. The strengthening of existing rigid pavements by overlays is covered by references. There is also a brief discussion of pavement structural requirements for jet aircraft as compared to present requirements for the more critical propeller-driven aircraft. The requirements for airport pavements given in this paper are limited to the pavement structure. Items such as runway and taxiway dimensional requirements for jet aircraft are not covered.

INTRODUCTION

There are a number of different approaches to the design of airfield pavements, several of which are discussed in a Committee Report of the Air Transport Division.(1) The design methods given in this paper are generally empirical and related to experience with full-scale traffic loading tests of specially-constructed test sections, as well as to observation of the effects of military jet aircraft on operational pavements. In the latter case the

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a. Presented at the October 1958 ASCE Convention in New York, N.Y.

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3. Engr., Rigid Pavement Lab., U.S. Army Engr. Ohio River Div. Labs., Cincinnati, Ohio.

loadings are more severe, both in magnitude and frequency, than can be anticipated during the next few years for commercial jet aircraft. Because of its experience with pavements serving jet aircraft, the Corps of Engineers has received frequent requests for pavement design information pertaining to commercial jet aircraft. For this reason the authors believed that the publication of a pavement design and evaluation procedure for these aircraft would provide a needed clarification of the problem, as well as provide additional information for those concerned with the design of commercial airport pavements.

Conditions of Design

The following table summarizes the loading and pavement contact conditions for the heavier commercial aircraft. These are the aircraft which have and will control the pavement requirements for any major commercial airport. The gross aircraft weights given in Table 1 are the present approximate maximum taxiing and take-off weights. Landing weights will be considerably lighter. In arriving at the main gear loading, eight per cent of the gross weight was assumed to be carried by the nose gear and the remaining load was assumed to be evenly divided between the two main gear. Thus, forty-six per cent of the gross weight is carried by each main gear. The

Table 1

Summary of Aircraft Loading Characteristics

Aircraft	Gross Weight (in Lbs)	Main Gear		Wheel Spacing (In.)	Tire Contact Area(In.^{2})
		Load (Lbs)	Configuration		
		Propeller-Driven Aircraft			
Douglas DC-7	122,200	58,100	Twin Wheels	30.75	214
Douglas DC-7C	143,000	68,000	Twin Wheels	29.75	269
Lockheed 1049-C	130,000	62,000	Twin Wheels	28.00	245
Lockheed 1649	160,000	75,600	Twin Wheels	30.00	262
Boeing 377	142,500	68,000	Twin Wheels	37.00	310
		Jet Aircraft			
Douglas DC-8	310,000	142,000	Twin Tandem	30X55	228
Boeing 707-320	296,000	136,200	Twin Tandem	34X56	236
Boeing 707-120	248,000	119,000	Twin Tandem	34X56	235
Convair 880	188,000	86,500	Twin Tandem	22.5 X45	152

main gear load is assumed to be distributed evenly on each of the four wheels of the gear. The tire contact area may be considered constant for all loadings, since aircraft tires are inflated to a constant deflection and the tire pressure allowed to vary with the load. The inflation pressure for a given load would be the load on the wheel divided by the contact areas given in the last column of Table 1. It is further assumed that the pressure of the tire on the pavement is uniform over the entire contact of the tire.

Another important condition that must be incorporated in pavement design is the number of maximum stress repetitions that the trafficked portion of the pavements will be required to sustain during their operational life. A maximum stress is considered to be the stress produced in the pavement when the aircraft operates at the design loading for the pavement. For the purpose of definition, the number of aircraft operations necessary to produce one maximum stress at each point in the trafficked area of a pavement feature is called a coverage. An operation is defined as one landing and one take-off. The number of coverages that the trafficked portion of an airfield pavement receives depends on the width of the tire contact area, the number of wheels in each main gear assembly and the lateral distribution of the aircraft operations during taxiing, landing or taking off. Based on the tire contact areas given in Table 1 and on the assumption that the lateral distribution of aircraft traffic would be such that seventy-five per cent of the operations occur within the central twenty-five feet of the trafficked areas, it is estimated that statistically eight operations would be equivalent to one coverage. The design charts given in this paper are for 5000 coverages. Due to the fact that the jet aircraft will not always operate at their maximum weight, nor will their operations be as frequent as those of lighter aircraft, it is believed that the use of 5000 coverages as a basis for design will provide for a pavement life of ten to twenty years at major airports.

If it can be determined that substantially more than 5000 coverages will be developed during the anticipated design life of the pavement, thicknesses obtained from the design charts given in this paper should be increased as shown in Table 2.

Table 2

Increase in Pavement Thickness for More than 5000 Coverages

Coverages	Increase in Pavement Thickness - %	
	Rigid Pavement	Flexible Pavement
10,000	5	7
15,000	8	11
20,000	10	14
30,000	12	18

Where the layout of airfield pavements is well established and ground operational movements of aircraft can be anticipated with a reasonable degree of certainty, further refinement in the design coverage levels assigned to the various pavement features may be justified.

Previous studies of ground movement of aircraft have shown that traffic will be most concentrated on the taxiways and loading ramps and be least concentrated in the interior portion of the runways. Runway interiors are

defined generally as the runway area exclusive of the 1000 feet at each end. Thicknesses determined from the design charts are for taxiways, loading ramps and runway ends. The runway interior will have its traffic more widely distributed, and loadings will be applied at higher aircraft speeds than on the other features. Therefore, it is approximately correct to reduce the taxiway design thickness ten per cent to arrive at the proper thickness for the pavement in the runway interior. This is applicable to both rigid and flexible pavements.

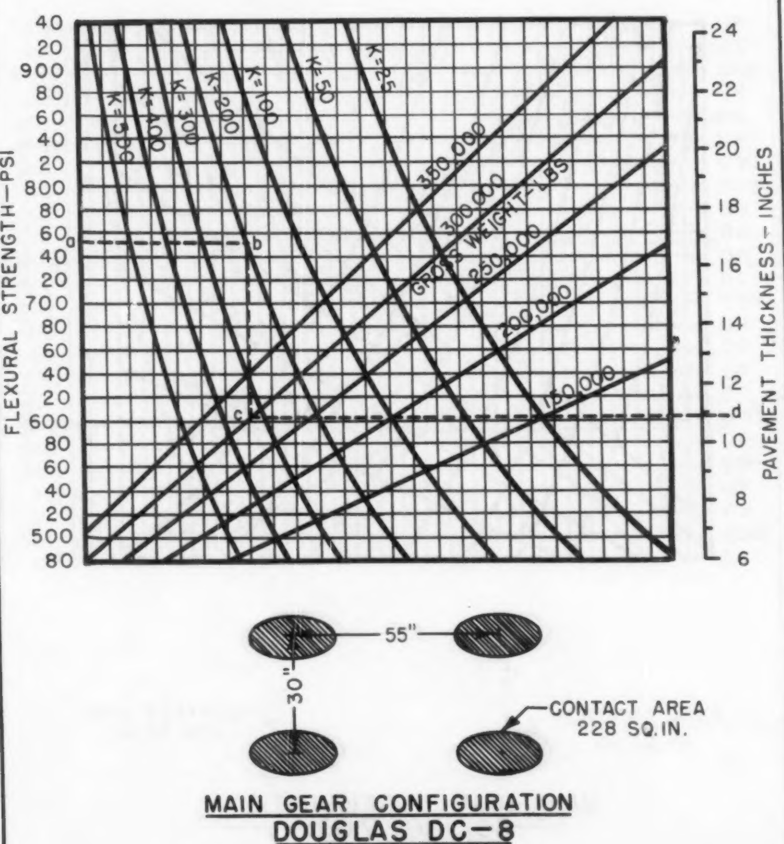
Rigid Pavement Design Charts

Design charts for determining the thickness of concrete required for the three commercial jet aircraft are given in Figs. 1, 2 and 3. The thicknesses obtained from these charts are recommended for taxiways, runway ends and loading ramps. For runway interiors, indicated thicknesses may be reduced by ten per cent. For design purposes, the required pavement thickness is determined by entering the charts at the flexural strength scale on the left hand ordinate, continuing horizontally to the appropriate "k" curve ("k" being the modulus of subgrade reaction in $lbs/in.^3$), then vertically to the design loading (maximum gross weight of aircraft), and finally horizontally to the pavement thickness scale on the right hand ordinate. An example is shown by the dotted lines ab, bc and cd on each chart. In using the design charts, if the fractional inch is 0.25 or greater, the thickness is rounded off to the next higher full inch. These charts can be used also for the evaluation of existing pavements if the thickness of concrete, the flexural strength of the concrete and the modulus of subgrade reaction "k" are known. This will give an evaluation in terms of the gross weight of the aircraft covered by the design charts.

Before going on to the applicable theory and assumptions which provide the basis for the design charts, it should be pointed out that the flexural strength used to enter the design charts is the 90-day flexural strength of the concrete determined by ASTM Designation C-78-49. The modulus of subgrade reaction "k" is determined from a 30-inch diameter plate bearing test as outlined in Reference (2).

Basic Theory and Modifications for Rigid Pavement Design Charts

The critical stress in a concrete pavement due to the loading of the twin-tandem gear configurations will occur along an edge or joint in the pavement. Since loading along a "free" or unsupported edge is not a consideration for airfield pavement design, the stress is computed for the critical load condition along a joint. This is done by using Westergaard's theoretical development as a basis for computing free edge stresses, and taking the joint into account by reducing the edge stress twenty-five per cent to allow for load transfer. Strain measurements with single, twin and twin-tandem wheel loadings at typical joints in full-scale test pavements indicate that the twenty-five per cent reduction in edge stress for the joint condition is generally conservative. The edge stress, so reduced, is the basic working stress for the design charts. The theoretical assumptions and computational methods are given by References (3), (4), and (5). The most critical



DESIGN CHART
FOR
CONCRETE AIRFIELD PAVEMENTS

FIGURE 1

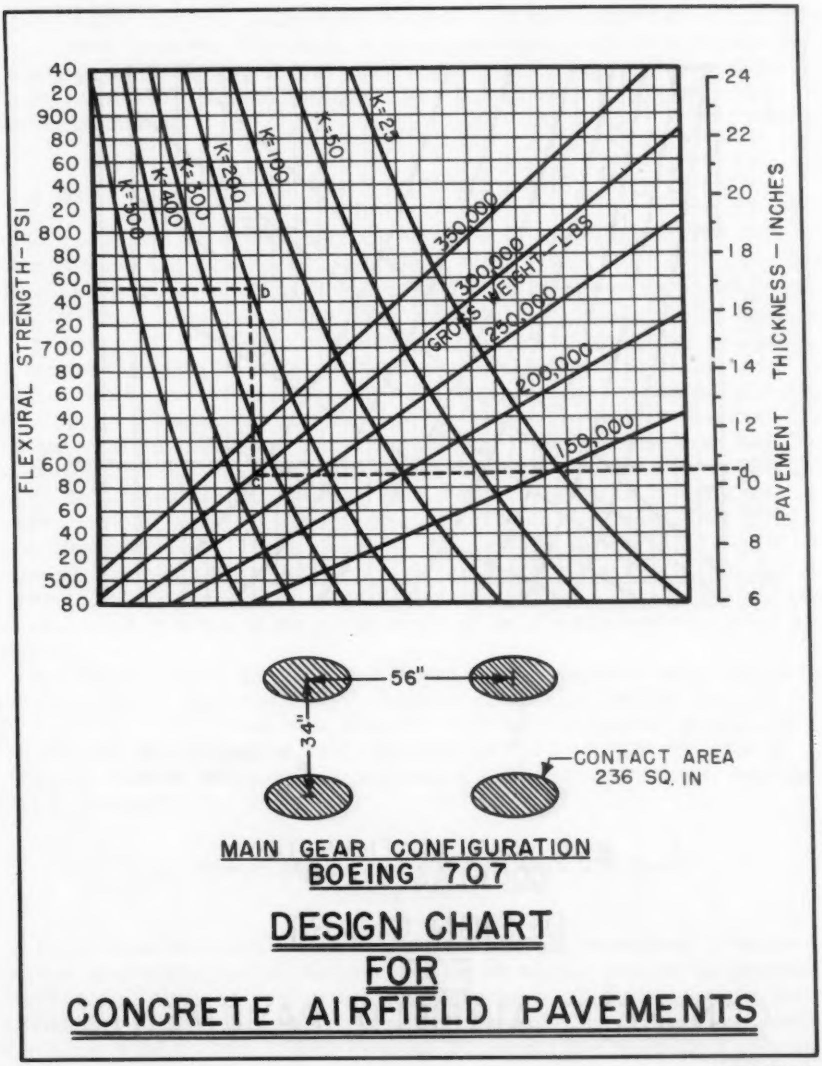
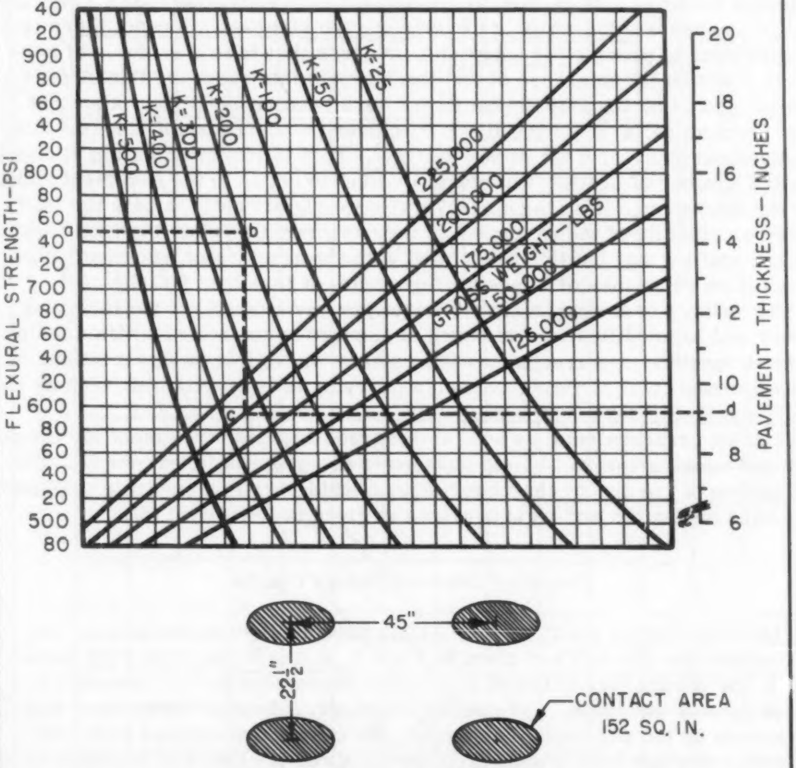

FLEXURAL STRENGTH - PSI
40
20
900
80
60
40
20
800
80
60
40
20
700
80
60
40
20
600
80
60
40
20
500
80
PAVEMENT THICKNESS - INCHES
24
22
20
18
16
14
12
10
8
6
K=500
K=400
K=300
K=200
K=100
K=50
K=25
GROSS WEIGHT - LBS
350,000
300,000
250,000
200,000
150,000
a
b
c
d
56"
34"
CONTACT AREA 236 SQ. IN
MAIN GEAR CONFIGURATION
BOEING 707
DESIGN CHART
FOR
CONCRETE AIRFIELD PAVEMENTS

FIGURE 2



MAIN GEAR CONFIGURATION
CONVAIR 880

DESIGN CHART FOR CONCRETE AIRFIELD PAVEMENTS

FIGURE 3

arrangement of the twin-tandem gear loading is with its longitudinal axis normal to the joint and two tire contact areas tangent to the point. For most cases, however, there is little difference in this stress and the maximum stress obtained with the longitudinal axis of the gear is parallel to the joint.

The design charts contain two modifications of the working stress. First, a design factor of 1.30 is used to account for load repetition (5,000 coverages) and to compensate for warping or temperature stresses. Second, there is a modification to provide for subgrades or bases that have a modulus of subgrade reaction "k" in excess of 200 lbs/in.^{3}. In this case, the thicknesses determined using the 1.30 design factor have been reduced approximately four per cent for a "k" of 300 lbs/in.^{3}, eleven per cent for 400 lbs/in.^{3} and nineteen per cent for a "k" of 500 lbs/in.^{3}. This latter modification allows a limited number of cracks (structural breaks) to occur in the pavement slabs during their design life. Such cracks will not significantly impair the load carrying capacity of the pavement as they will remain relatively intact without the spalling and faulting associated with the cracking of pavements constructed on subgrades or bases having moduli of less than 200 lbs/in.^{3}

The validity of the application to rigid pavement design of the foregoing theory and its modifications is based on numerous controlled traffic loading tests of specially constructed test pavements, as well as on observations of the performance of airfield pavements carrying military aircraft such as the B-47, and B-52, B-29, and B-36.

Jointing arrangements, as well as subgrade and base treatment for the design and construction of airfield pavements are given in Reference (2). The application of the design charts for strengthening existing concrete pavements by means of flexible and rigid overlays is given in Reference (6).

Flexible Pavement Design Charts

Thickness design relations for flexible pavements to accommodate the commercial jet aircraft are given in Figs. 4, 5, and 6. As with rigid pavements, the thicknesses obtained from these curves are for all pavements except runway interiors. For runway interiors, indicated thicknesses may be reduced by ten per cent. For design, the curves are entered with CBR and gross aircraft load to determine the required thickness of stronger overlying construction. Evaluations of existing pavements can be made merely by entering these curves with CBR's and existing thicknesses to arrive at a permissible gross aircraft load. The curves in Figs. 4, 5, and 6 extend only to 3 CBR since it is considered that weaker subgrades normally should not be considered suitable for airfields. Each figure, however, includes a tabulation of protective thicknesses of cover for 1, 2, and 3 CBR strengths. Exploration should be carried at least to the depth, below final grade, indicated by thickness requirements for 1 CBR. Strengths of soft layers encountered must be evaluated and the necessary protective thickness of cover determined to be present or provided.

Basis of Flexible Pavement Design

Design thicknesses at the subgrade and subbase level for flexible pavements are determined, by Corps of Engineers criteria, from the CBR design curves (See Figs. 4, 5 and 6). Background information on development of

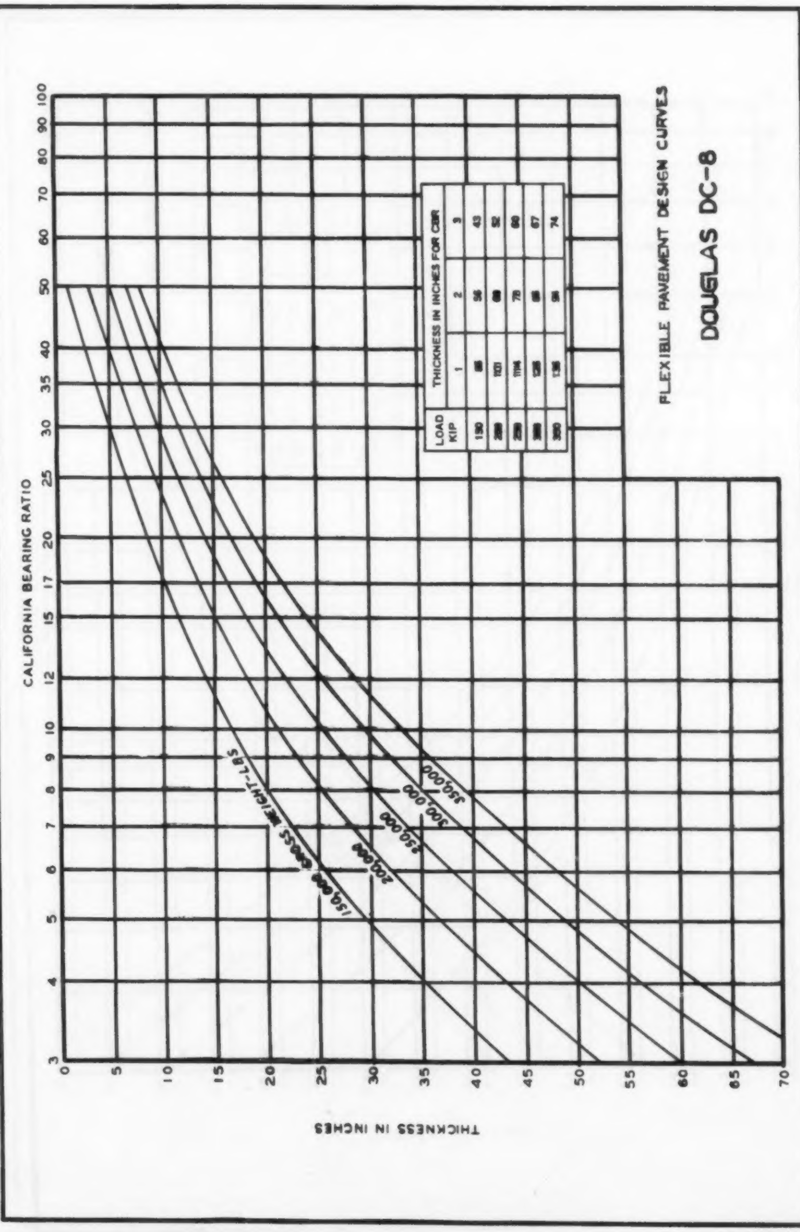
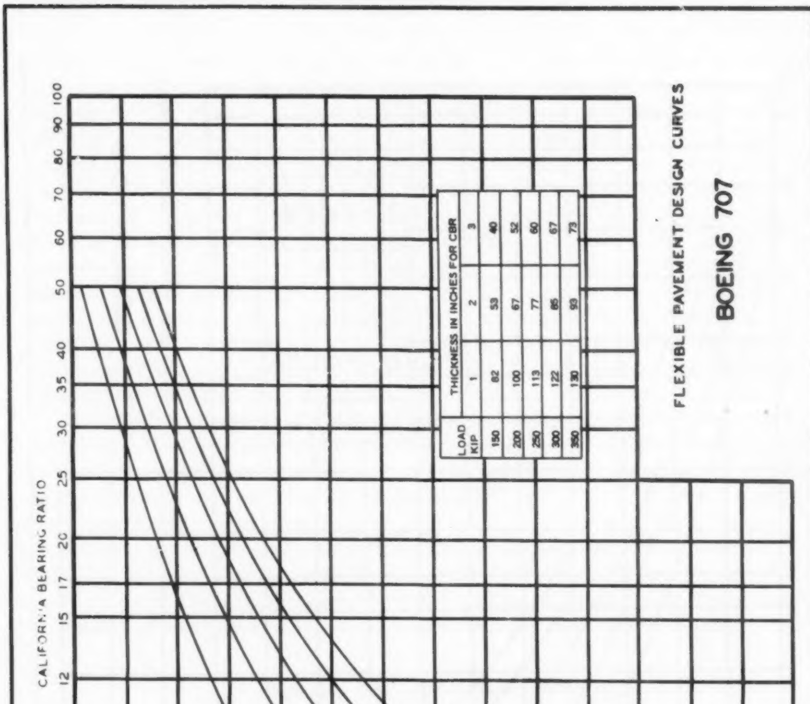

FLEXIBLE PAVEMENT DESIGN CURVES
DOUGLAS DC-8
CALIFORNIA BEARING RATIO
THICKNESS IN INCHES
GROSS WEIGHT-LBS
150,000
200,000
250,000
300,000
350,000
LOAD KIP
THICKNESS IN INCHES FOR CBR

FIGURE 4



LOAD KIP	THICKNESS IN INCHES FOR CBR 1	2	3
150	82	53	40
200	100	67	52
250	113	77	60
300	122	85	67
350	130	93	73

FIGURE 5

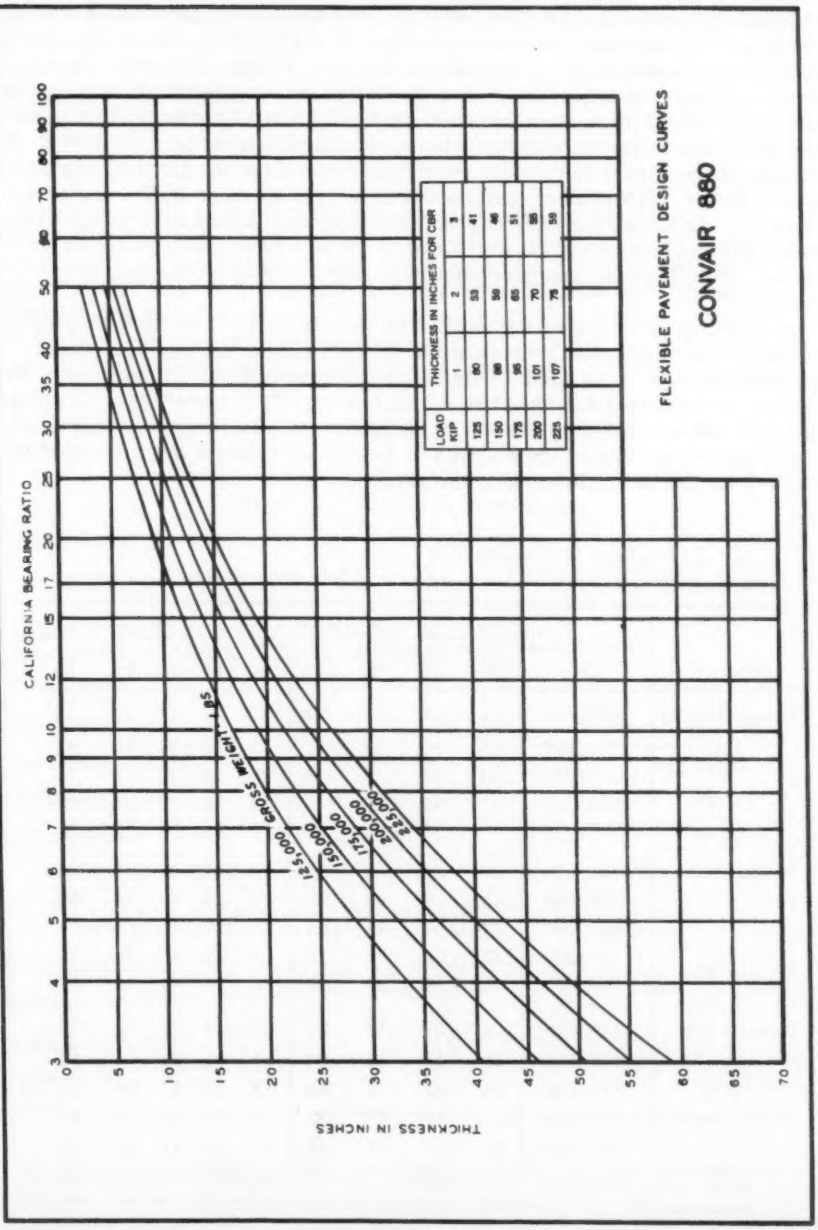

FLEXIBLE PAVEMENT DESIGN CURVES
CONVAIR 880
CALIFORNIA BEARING RATIO
THICKNESS IN INCHES
GROSS WEIGHT - LBS
125,000
150,000
175,000
200,000
225,000
LOAD KIP
THICKNESS IN INCHES FOR CBR
1 2 3
125 80 53 41
150 88 58 46
175 95 65 51
200 101 70 55
225 107 78 59
3 4 5 6 7 8 9 10 12 15 17 20 25 30 35 40 50 60 70 80 90 100
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70

FIGURE 6

CBR curves may be found in References (7), (9), (10), and (11). It is considered that subbase materials used in high-type airfield pavements should not be given a strength rating greater than 50 CBR. Thus, the design curves in Figs. 4, 5 and 6 do not extend above 50 CBR. Design thickness requirements for pavements and bases are dominated by considerations of stability and longevity. Tire contact pressure is more important than loading in base and pavement thickness determinations, though both must be considered. It usually is necessary to tabulate requirements; but for the aircraft considered in this paper, requirements can be stated merely as three inches for pavement and six inches for base course. This contemplates use of a high-type pavement and base material which can be given a CBR rating of eighty or better. Detailed base and pavement requirements may be found in Reference (8).

In addition to providing the necessary resistance to shear deformation in a flexible pavement, the consolidation which results from repeated wheel loadings must be controlled. This is accomplished by gaining sufficient compaction of materials during construction that significant additional consolidation will not occur during the life of the pavement. To this end, compaction requirements developed from Corps of Engineers criteria are presented in Table 3 for the aircraft being considered:—

Table 3

Required Depth of Compaction Beneath Flexible Airfield Pavements

Aircraft	Gross Load Lb.	Required Compaction - Per Cent Modified AASHO								
		Cohesionless Mat'ls.				Cohesive Materials				
		100	95	90	85	100	95	90	85	80
Douglas DC-8	150,000	19	38	58	77	10	19	29	40	52
	200,000	23	46	69	91	13	23	36	49	62
	250,000	28	53	79	104	15	28	42	56	71
	300,000	32	60	88	114	18	32	48	63	79
	350,000	36	66	95	124	20	36	53	69	87
Boeing 707	150,000	17	35	54	73	9	17	26	37	48
	200,000	23	46	68	90	12	23	35	48	62
	250,000	27	53	78	103	15	27	41	56	71
	300,000	32	59	87	112	17	32	47	62	79
	350,000	36	65	95	120	20	36	52	69	86
Convair 880	125,000	18	36	54	72	10	18	28	38	48
	150,000	21	41	60	80	12	21	32	43	54
	175,000	24	45	66	86	13	24	35	47	60
	200,000	26	49	72	92	15	26	39	51	65
	225,000	29	53	77	98	16	29	42	55	70

NOTE: Depths are in inches measured from finished grade.

While the depths indicated for the various percentages of compaction are more than merely a guide to requirements, it is always necessary to provide

for the occasional materials which can be compacted appreciably more or less readily than average materials. Specific statements of these or any requirements, without provision for unexpected situations, can lead to trouble. Reference (8), may be used as a guide in establishing provisions for such unexpected developments.

CONCLUSION

It is interesting to compare the pavement thickness requirements for propeller-driven and jet aircraft for the loadings listed in Table 1. In the case of rigid pavements this is done for an assumed concrete flexural strength of 700 psi and a subgrade modulus "k" of 200 $lbs/in.^3$. In the case of flexible pavements a subgrade CBR value of 12 is used, which is comparable to a subgrade modulus of 200 $lbs/in.^3$. Table 4 gives this comparison of pavement thickness for both types of pavements.

Table 4

Comparative Thickness Requirements for Rigid and Flexible Pavements

Aircraft	Pavement Thickness, Inches	
	Rigid	Flexible
Propeller-Driven Aircraft		
Douglas DC-7	11	19
Douglas DC-7C	12	21
Lockheed 1049-C	12	20
Lockheed 1649	13	22
Boeing 377	11	19
Jet Aircraft		
Douglas DC-8	12	26
Boeing 707-320	11	25
Boeing 707-120	10	21
Convair 880	9	20

The pavement thicknesses for jet aircraft given in Table 4 are taken directly from the design charts shown in Figs. 1 through 6. Thicknesses shown for propeller-driven aircraft were computed from the same basic criteria relating load, stress and the effects of load repetition as were used in the design charts for the jet aircraft.

It can be seen that, in general, commercial airport pavements constructed of portland cement concrete and adequately designed for the presently operating propeller-driven aircraft listed in Table 4 will not be overloaded by the jet aircraft at their present gross weights. This is largely attributable to the use of twin-tandem wheel assemblies on the main gear of the jet aircraft. For rigid pavements in the order of eight to twelve-inches thick, the use of a twin-tandem configuration is particularly efficient as a means of load distribution. For flexible pavements, somewhat less efficiency in load distribution is obtained with the result that increases in thickness of fifteen to twenty per cent are indicated as being necessary to provide adequately designed pavements.

It should be pointed out, however, it is to be anticipated that gross weights of these jet aircraft will increase just as have those of propeller-driven aircraft and military jet aircraft. Increases in gross weights of commercial jet aircraft of ten to twenty per cent over the next five to ten years are not improbable. It is believed important that engineers responsible for new airport pavement facilities be cognizant of this "growth factor" and incorporate it in present day design.

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Mr. J. E. Steiner, Transport Division, Boeing Airplane Company.

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CONTENTS

DISCUSSION

AIRCRAFT OPERATIONS ON FLOATING ICE SHEETS[a]

Closure by S. Russell Stearns

S. RUSSELL STEARNS,[1] A.M. ASCE.—The author thanks Col. Louis DeGoes for his discussion which gives additional pertinent information particularly in the field of operations of aircraft in polar regions.

Col. DeGoes notes the variable nature of ice, and the difficulty of predicting its thickness from examination of general regional weather records. Although the exact thickness at a pinpointed location is not possible of determination from afar, particularly in areas of heavy snowfall, general trends and approximate limits for safe operation can be established from temperature records. This is especially true in areas of low snowfall. It must be emphasized again, though, that thickness determination is not sufficient. The physical, or strength, properties of the ice must be ascertained if one is to reduce the "factor of safety" to a reasonable figure.

Col. DeGoes has raised some pertinent questions relative to the elastic properties of ice. Ice is an elastic-plastic material and its deformation characteristics depend upon loading rate. A family of stress-strain curves results from various loading rates, and only for relatively rapid loading is a linear stress-strain relationship obtained. This straight line relationship continues to failure, as is typical of many brittle materials. Under static loading, and for slow moving vehicles, the deformation is predominately plastic, and no elastic limit, or proportional limit, is noted. The material acts more like cast iron or concrete. It has been demonstrated by Butkovitch[(12)*] that for a loading of 0.5 $Kg/cm^2/sec$, or faster, ice acts as an elastic material, and the plastic deformation, or creep, can be considered negligible.

Col. DeGoes asks about the correlation of the first crack in the ice sheet to the stress-strain curve, and its elastic limit. It will be recalled that the first crack occurs in the bottom of the ice sheet, under the load. This is a tensile crack which results when tensile stress exceeds tensile strength in the extreme bottom fiber. This is the fracture point of the stress-strain curve and has no relation to elastic limit or proportional limit if any exist. The value of the stress is computed from the familiar flexure formula which assumes elastic behavior. Thus this computed stress is approximate only. The shape of the stress-strain curve for ice, as noted above, depends upon loading rate. It varies from straight line (fast loading and brittle behavior) to a very flat curve of decreasing slope (slow or static loading and plastic behavior). In neither case, to this writer's knowledge, has a true elastic

a. Proc. Paper 1325, July, 1957, by S. Russell Stearns.

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* References 1-11 are included in the original paper.

limit or proportional limit been noted. These references dealing with the strength properties of ice may be of interest.(13,14,15,16,17)

Time certainly is a factor for static loading, and additional testing of this type should be undertaken to obtain a better picture of progressive creep.

The relation of ice thickness to load influence radius was given in Fig. 2 in the original paper. This relationship is based on the theory of elasticity, and additional information should be obtained for long period loading and plastic action. Some of this information is now at hand, although unpublished, as a result of subsequent, extensive operations and observations in the Arctic and Antarctic where ice sheet loading strips have become the critical key in the airlift support.

It is doubtful that temperature stresses have any effect, as prestress, on the first cracking since this cracking is in bottom ice at the very well regulated, constant temperature of the water surface. The effect of prestress on final (top surface) cracking may be quite substantial, but, again here, the largest temperature stresses occur at the coldest temperatures (contraction stresses) when the ice is strongest. This prestress effect should be studied nevertheless.

It is necessary to repeat that once ice has reached required thicknesses, based on accepted factors of risk, the most critical period is during thaw when the surface becomes melted and pockmarked. The thickness may be adequate, but the surface must be repaired or operations will of necessity be curtailed.

A final word of caution is necessary in regard to building up ice thickness by pumping. One must avoid the use of too large a quantity of water, especially salt water, or dangerous shelf ice may result.

Col. DeGoes' interesting and informative discussion is most appreciated.

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These papers are printed as Technical Memorandum No. 56 Reprinted from Transactions, Engineering Institute of Canada, Vol. 2 No. 3, October 1958, Ottawa. (N.R.C. 4928).

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* Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U.S. Army.

USAF AIRFIELD PAVEMENT PROBLEMS IN THE JET AGE[a]

Closure by George W. Leslie

GEORGE W. LESLIE.[1]—From the discussions by Mr. Gardner and Mr. Bascom one gathers the impression that this paper was a per se condemnation of asphaltic pavement for airfield use. Such is not the case. Simply stated, the choice of using rigid pavement for other than the originally designated critical areas (aprons, hardstands, runway ends, etc.), boils down to the fact that a multi-layered flexible pavement system is more difficult to design and construct than a rigid pavement slab. The series of failures of flexible pavement which was experienced was partly due to either design or construction errors (which Mr. Gardner concedes) and to unexpected stresses imposed by the aircraft. In studying these problems preliminary investigations indicated that rigid pavement designs offered a more readily available solution. Under the circumstances, the choice was obvious.

Contrary to Mr. Gardner's opinion of the accelerated test at Kelly Air Force Base, the test proved that the proposed design for the bituminous concrete mix to support the specified requirements was inadequate and that the rigid pavement design was adequate. All investigations of this type provide valuable data for further study.

As any engineer who is acquainted with the design and construction of pavements knows, rigid pavements are not without their faults, too. However, in all fairness it must be pointed out that none of the rigid pavements designated and constructed for the same requirements as specified for flexible pavements and subjected to the same type traffic as the flexible pavements have required any major repair.

Investigations are continuing with the hope that new materials and methods of constructing pavements will be developed which will be superior and more economical than those now known.

a. Proc. Paper 1480, December, 1957, by George W. Leslie.

1. Cons. Civ. Eng., Directorate of Construction, U.S. Air Force, Washington, D.C.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1859 is identified as 1859 (HY 7) which indicates that the paper is contained in the seventh issue of the Journal of the Hydraulics Division during 1958.

VOLUME 84 (1958)

MAY: 1621(HW2), 1622(HW2), 1623(HW2), 1624(HW2), 1625(HW2), 1626(HW2), 1627(HW2), 1628(HW2), 1629 (ST3), 1630(ST3), 1631(ST3), 1632(ST3), 1633(ST3), 1634(ST3), 1635(ST3), 1636(ST3). 1637(ST3), 1638(ST3), 1639 (WW3), 1640(WW3), 1641(WW3), 1642(WW3), 1643(WW3), 1644(WW3), 1645(SM2), 1646(SM2), 1647 (SM2), 1648(SM2), 1649(SM2), 1650(SM2), 1651(HW2), 1652(HW2)c, 1653(WW3)c, 1654(SM2), 1655(SM2), 1656(ST3)c, 1657(SM2)c.

JUNE: 1658(AT1), 1659(AT1), 1660(HY3), 1661(HY3), 1662(HY3), 1663(HY3), 1664(HY3), 1665(SA3), 1666 (PL2), 1667(PL2), 1668(PL2), 1669(AT1), 1670(PO3), 1671(PO3), 1672(PO3), 1673(PL2), 1674(PL2), 1675 (PO3), 1676(PO3), 1677(SA3), 1678(SA3), 1679(SA3), 1680(SA3), 1681(SA3), 1682(SA3), 1683(PO3), 1684 (HY3), 1685(SA3), 1686(SA3), 1687(PO3), 1688(SA3)c, 1689(PO3)c, 1690(HY3)c, 1691(PL2)c.

JULY: 1692(EM3), 1693(EM3), 1694(ST4), 1695(ST4), 1696(ST4), 1697(SU2), 1698(SU2), 1699(SU2), 1700(SU2), 1701(SA4), 1702(SA4), 1703(SA4), 1704(SA4), 1705(SA4), 1706(EM3), 1707(ST4), 1708(ST4), 1709(ST4), 1710 (ST4), 1711(ST4), 1712(ST4), 1713(SU2), 1714(SA4), 1715(SA4), 1716(SU2), 1717(SA4), 1718(EM3), 1719 (EM3), 1720(SU2), 1721(ST4)c, 1722(ST4), 1723(ST4), 1724(EM3)c.

AUGUST: 1725(HY4), 1726(HY4), 1727(SM3), 1728(SM3), 1729(SM3), 1730(SM3), 1731(SM3), 1732(SM3), 1733 (PO4), 1734(PO4), 1735(PO4), 1736(PO4), 1737(PO4), 1738(PO4), 1739(PO4), 1740(PO4), 1741(PO4), 1742 (PO4), 1743(PO4), 1744(PO4), 1745(PO4), 1746(PO4), 1747(PO4), 1748(PO4), 1749(PO4).

SEPTEMBER: 1750(IR3), 1751(IR3), 1752(IR3), 1753(IR3), 1754(IR3), 1755(ST5), 1756(ST5), 1757(ST5), 1758(ST5), 1759(ST5), 1760(ST5), 1761(ST5), 1762(ST5), 1763(ST5), 1764(ST5), 1765(WW4), 1766(WW4), 1767(WW4), 1768(WW4), 1769(WW4), 1770(WW4), 1771(WW4), 1772(WW4), 1773(WW4), 1774(IR3), 1775 (IR3), 1776(SA5), 1777(SA5), 1778(SA5), 1779(SA5), 1780(SA5), 1781(WW4), 1782(SA5), 1783(SA5), 1784 (IR3)c, 1785(WW4)c, 1786(SA5)c, 1787(ST5)c, 1788(IR3), 1789(WW4).

OCTOBER: 1790(EM4), 1791(EM4), 1792(EM4), 1793(EM4), 1794(EM4), 1795(HW3), 1796(HW3), 1797(HW3), 1798(HW3), 1799(HW3), 1800(HW3), 1801(HW3), 1802(HW3), 1803(HW3), 1804(HW3), 1805(HW3), 1806 (HY5), 1807(HY5), 1808(HY5), 1809(HY5), 1810(HY5), 1811(HY5), 1812(SM4), 1813(SM4), 1814(ST6), 1815 (ST6), 1816(ST6), 1817(ST6), 1818(ST6), 1819(ST6), 1820(ST6), 1821(ST6), 1822(EM4), 1823(PO5), 1824 (SM4), 1825(SM4), 1826(SM4), 1827(ST6)c, 1828(SM4)c, 1829(HW3)c, 1830(PO5)c, 1831(EM4)c, 1832(HY5)c

NOVEMBER: 1833(HY6), 1834(HY6), 1835(SA6), 1836(ST7), 1837(ST7), 1838(ST7), 1839(ST7), 1840(ST7), 1841(ST7), 1842(SU3), 1843(SU3), 1844(SU3), 1845(SU3), 1846(SU3), 1847(SA6), 1848(SA6), 1849(SA6), 1850(SA6), 1851(SA6), 1852(SA6), 1853(SA6), 1854(ST7), 1855(SA6)c, 1856(HY6)c, 1857(ST7)c, 1858 (SU3)c.

DECEMBER: 1859(HY7), 1860(IR4), 1861(IR4), 1862(IR4), 1863(SM5), 1864(SM5), 1865(ST8), 1866(ST8), 1867 (ST8), 1868(PP1), 1869(PP1), 1870(PP1), 1871(PP1), 1872(PP1), 1873(WW5), 1874(WW5), 1875(WW5), 1876 (WW5), 1877(CP2), 1878(ST8), 1879(ST8), 1880(HY7)c, 1881(SM5)c, 1882(ST8)c, 1883(PP1)c, 1884(WW5)c, 1885(CP2)c, 1886(PO6), 1887(PO6), 1888(PO6), 1889(PO6), 1890(HY7), 1891(PP1).

VOLUME 85 (1959)

JANUARY: 1892(AT1), 1893(AT1), 1894(EM1), 1895(EM1), 1896(EM1), 1897(EM1), 1898(EM1), 1899(HW1), 1900(HW1), 1901(HY1), 1902(HY1), 1903(HY1), 1904(HY1), 1905(PL1), 1906(PL1), 1907(PL1), 1908(PL1), 1909(ST1), 1910(ST1), 1911(ST1), 1912(ST1), 1913(ST1), 1914(ST1), 1915(ST1), 1916(AT1)c, 1917(EM1)c, 1918(HW1)c, 1919(HY1)c, 1920(PL1)c, 1921(SA1)c, 1922(ST1)c, 1923(EM1), 1924(HW1), 1925(HW1), 1926 (PL1), 1927(HW1), 1928(HW1), 1929(SA1), 1930(SA1), 1931(SA1), 1932(SA1).

FEBRUARY: 1933(HY2), 1934(HY2), 1935(HY2), 1936(SM1), 1937(SM1), 1938(ST2), 1939(ST2), 1940(ST2), 1941(ST2), 1942(ST2), 1943(ST2), 1944(ST2), 1945(HY2), 1946(PO1), 1947(PO1), 1948(PO1), 1949(PO1), 1950(HY2)c, 1951(SM1)c, 1952(ST2)c, 1953(PO1)c, 1954(CO1), 1955(CO1), 1956(CO1), 1957(CO1), 1958 (CO1), 1959(CO1).

MARCH: 1960(HY3), 1961(HY3), 1962(HY3), 1963(IR1), 1964(IR1), 1965(IR1), 1966(IR1), 1967(SA2), 1968 (SA2), 1969(ST3), 1970(ST3), 1971(ST3), 1972(ST3), 1973(ST3), 1974(ST3), 1975(ST3), 1976(WW1), 1977 (WW1), 1978(WW1), 1979(WW1), 1980(WW1), 1981(WW1), 1982(WW1), 1983(WW1), 1984(SA2), 1985(SA2)c, 1986(IR1)c, 1987(WW1)c, 1988(ST3)c, 1989(HY3)c.

APRIL: 1990(EM2), 1991(EM2), 1992(EM2), 1993(HW2), 1994(HY4), 1995(HY4), 1996(HY4), 1997(HY4), 1998 (SM2), 1999(SM2), 2000(SM2), 2001(SM2), 2002(ST4), 2003(ST4), 2004(ST4), 2005(ST4), 2006(PO2), 2007 (HW2)c, 2008(EM2)c, 2009(ST4)c, 2010(SM2)c, 2011(SM2)c, 2012(HY4)c, 2013(PO2)c.

MAY: 2014(AT2), 2015(AT2), 2016(AT2), 2017(HY5), 2018(HY5), 2019(HY5), 2020(HY5), 2021(HY5), 2022 (HY5), 2023(PL2), 2024(PL2), 2025(PL2), 2026(PP1), 2027(PP1), 2028(PP1), 2029(PP1), 2030(SA3), 2031(SA3), 2032(SA3), 2033(SA3), 2034(ST5), 2035(ST5), 2036(ST5), 2037(ST5), 2038(PL2), 2039(PL2), 2040(AT2)c, 2041(PL2)c, 2042(PP1)c, 2043(ST5)c, 2044(SA3)c, 2045(HY5)c, 2046(PP1), 2047(PP1).

c. Discussion of several papers, grouped by divisions.

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